Published in final edited form as:

Int Forum Allergy Rhinol. 2015 July ; 5(7): 637–642. doi:10.1002/alr.21499.

Computer-Assisted Staging of Chronic Rhinosinusitis Correlates with Symptoms

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Abstract

Objectives—The Lund-Mackay (LM) staging system for Chronic Rhinosinusitis (CRS) does not correlate with clinical parameters, likely due to its coarse scale. We developed a “Modified Lund Mackay” (MLM) system, which uses a 3D, computerized method to quantify the volume of mucosal inflammation in the sinuses, and sought to determine whether the MLM would correlate with symptoms and disease-specific quality of life.

Methods—We obtained Total Nasal Symptom Score (TNSS) and Sinonasal Outcomes Test (SNOT-22) data from 55 adult subjects immediately prior to sinus imaging. The volume of each sinus occupied by mucosal inflammation was measured using MATLAB algorithms created using customized, image analysis software after manual outlining of each sinus. Linear regression was used to model the relationship between the MLM and SNOT-22 and TNSS. Correlation between the LM and MLM was tested using Spearman's rank correlation coefficient.

Results—Adjusting for age, gender, and smoking, a higher symptom burden was associated with increased sinonasal inflammation as captured by the MLM ($\beta=0.453$, $p<0.013$). As expected due to the differences in scales, the LM and MLM scores were significantly different ($p<0.011$). No association between MLM and SNOT-22 scores was found.

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Disclosures: SGA receives royalties and licensing fees for computer-aided diagnosis technology through the University of Chicago. All other authors declare no conflicts.

This work was presented at the 2014 American Academy of Otolaryngic Allergy and the American Rhinologic Society meetings in Orlando, FL.

Conclusions—The MLM is one of the first imaging-based scoring systems that correlates with sinonasal symptoms. Further development of this custom software, including full automation and validation in larger samples, may yield a biomarker with great utility for both treatment of patients and outcomes assessment in clinical trials.

Keywords

sinusitis; chronic sinusitis; symptoms; computed tomography; computer-assisted image analysis; quality of life; Lund-Mackay; sinonasal

INTRODUCTION

Chronic rhinosinusitis (CRS) is a highly prevalent disease posing a substantial economic burden on the healthcare system [1]. Although significant effort has been devoted to investigating its pathophysiologic basis, efficacy of various therapies, and utility of diagnostic tools such as imaging and endoscopy, our understanding of these areas remains limited. A major barrier to progress in developing effective treatments is the lack of a biomarker for use in the evaluation of treatment efficacy. Thus, no therapies for CRS have been approved by the United States Food and Drug Administration (FDA) because there is no measure by which to validate them.

The most recent practice guidelines for CRS recommend radiologic evaluation with computed tomography (CT) imaging of the paranasal sinuses [2] for a variety of reasons, including assessment of disease extent and surgical planning [3]. Though clinically employed to localize and quantify chronic mucosal inflammation [4], common CT-based staging systems [5] have failed to correlate with disease severity, so use of these systems remains controversial [6]. The most widely used scoring system is the Lund-Mackay (LM) system [7], which assigns to each of 10 sinus cavities (left and right maxillary, anterior ethmoid, posterior ethmoid, sphenoid, and frontal) a score of 0 (no opacification), 1 (partial opacification), or 2 (total opacification) based on the extent of mucosal thickening within that sinus, plus a 0-2 score for the ostiomeatal complex (OMC). The total LM score for a CT scan ranges from 0-24. This system has been lauded for its low inter-observer variability, objectivity, and ease of use [8, 9], but it does not correlate strongly with either patient symptoms or quality of life (QOL) [10], likely due to its inability to distinguish among varying degrees of “partial opacification.” Zinreich [11] modified the LM system by creating subdivisions within “partial opacification” and increasing the range of scores to 0-5 based on percent opacification: 0 = 0%, 1 = 1%-25%, 2 = 26%-50%, 3 = 51%-75%, 4 = 76%-99%, and 5 = 100%. Such an expanded range of scores with finer resolution, however, leads to increased variability. Okushi et al. [12] attempted to modify the LM system by calculating percent opacification across CT sections. These authors did not assess the correlation between their LM scores and clinical symptoms, and their LM scoring system did not demonstrate clear superiority over the traditional LM staging system. The ideal scoring system for CRS imaging should combine elements of objectivity, simplicity, low inter-observer variability, and fine resolution. Software automation might achieve these goals.

To meet this need, a novel software-based tool was developed to assess mucosal thickening using three-dimensional (3D), volumetric analysis. Image analysis has been utilized in various areas of otolaryngology, including sinus disease [13]. For example, Deeb et al. [14] used a computer program to investigate mucosal changes at the level of the maxillary sinuses based on manual outlines. Likness et al. [15] compared image-based CRS scoring systems by using volumetric calculations from CT scans as an objective measure of inflammation. Pallanch et al. [16] compared quantitative measurements of inflammation to symptoms and endoscopic examination findings.

In contrast to these previous studies, the software tool described in the present study uses a volumetric analysis technique to measure mucosal thickening of each paranasal sinus cavity and calculates a quantitative modification to the LM score, a “modified Lund-Mackay” (MLM) score, on a continuous scale. This study evolved from the hypothesis that the computerized, volume-based MLM score would correlate more strongly than the visual, subjective LM score with quality of life and symptoms.

METHODS

Patients

Fifty-five adults undergoing routine sinus CT imaging at The University of Chicago were recruited to participate. Indications for imaging were unknown to the investigators and were based solely at the discretion of the ordering physicians who were not involved in the study; thus, the patients were not characterized for sinonasal disease and had a range of severity consistent with a sample of primary care patients. The study included adults (≥ 18 years of age) who were cognitively capable of providing written consent. The only exclusion criterion was refusal to provide written consent. Image data were collected, anonymized by the Human Imaging Research Office [17], and processed as described below. Immediately prior to image acquisition, patients completed two validated surveys, the Sinonasal Outcomes Test-22 (SNOT-22) and the Total Nasal Symptom Score (TNSS). The SNOT-22 is a quality of life-related measure of sinonasal function consisting of 22 questions rated from 0 (no problem) to 5 (Problem as bad as it can be) with a theoretical range of 0-110 and higher scores indicative of poorer nasal function [18]. The TNSS is a 4-item questionnaire used to rate severity of sinonasal symptoms (sneezing, runny nose, stuffy nose and other) on a scale of 0 (none) to 3 (severe) with a theoretical range of 0-12 and higher scores associated with increased symptom severity [19]. Demographic information including age, gender, and smoking status was also collected (Table 1). Written, informed consent was obtained for all subjects, and the Institutional Review Board approved the study.

Three-Dimensional Volumetric Analysis

Using an in-house software system (ABRAS), manual segmentations of the CT images were constructed for each patient. ABRAS is an image visualization and manipulation tool that allows for window adjustment, magnification, and visualization for all sections of a CT scan [20]. All sinus cavities were outlined by trained observers [MKF, MR], who manually constructed outlines along the bony landmarks that define the sinuses (excluding the OMC) in each CT section image (Figure 1). ABRAS allows the user to label the anatomic location

(maxillary, anterior or posterior ethmoid, sphenoid, or frontal) of individual sinus outlines. All outlines were reviewed for accuracy by one of three experts in sinonasal imaging, two board-certified neuroradiologists [DTG, CSP] and a board-certified rhinologist [JP]. LM scores were assigned to each subject's scan separately in a similar fashion. Persons outlining, reviewing, and scoring these scans were blinded to all clinical characteristics and survey data for the subjects.

Modified Lund-Mackay score

The sinus outlines then were exported to the volumetric analysis software tool developed by our group [21]. This algorithm uses gray-level thresholding methods to subtract all airspace pixels contained within an outline from the total area encompassed by the outline to calculate the area occupied by inflammation within the outline in a single CT section image. Then, the algorithm sums these areas for individual sinuses across CT sections to yield (1) the total volume of inflammation, (2) the total sinus volume, and (3) the ratio of mucosal inflammation to sinus volume for each sinus. The MLM score then was calculated for each sinus cavity by multiplying the mucosa-to-sinus volume ratio (a continuous value between 0 and 1) by 2 to preserve the same range of values as the traditional LM system (which assigns a discrete value of 0, 1, or 2 to each sinus). The total MLM score was obtained by summing the MLM scores for all sinuses in a scan; the total LM score was obtained in an analogous manner. The OMC was excluded from both MLM and LM scores due to its nonstandard anatomic boundaries.

MLM scores were compared with LM scores, and the association of both scores with SNOT-22 and TNSS scores was evaluated. Multivariate regression models were constructed to investigate trends between scoring methods and the symptom severity measures. The impact of specific anatomic location on correlation also was evaluated.

Statistical Analysis

Statistical analysis was performed using R-Console (www.r-project.org). Comparison of the LM and MLM scores was by the Mann-Whitney U test after both datasets were determined to have non-normal distributions by the Shapiro-Wilk test. Multivariate linear regression models were constructed with MLM as the dependent variable using TNSS and SNOT-22 scores as independent variables, with age, gender, and tobacco use as covariates. To investigate specific sinus MLM scores, stepwise regression was used to guide the selection of individual sinuses. The results of stepwise regression indicated that a combination of MLM scores from maxillary, ethmoid and frontal sinuses would achieve the best model fit (indicated by Akaike information criterion) [22]. Multivariate regression models then were constructed to examine the effect of individual maxillary, ethmoid, and frontal sinus MLM scores on (1) patient symptom scores and (2) patient quality of life scores.

RESULTS

Total LM scores across all 55 patients ranged from 0 to 18, and total MLM scores ranged from 0.67 to 18.3 (Table 1). As expected due to differences in scale, the mean LM score was lower than the mean MLM score (3.9 ± 3.9 , 4.9 ± 3.6 , $p=0.011$).

Multivariate regression models were constructed to analyze the relationship between imaging findings and clinical parameters. In bivariate analysis, increased symptom scores (i.e., increased TNSS) were associated with greater mucosal inflammation as captured by the MLM score ($\beta=0.437$, $p=0.014$). Including age, gender, and smoking status strengthened this finding slightly ($\beta=0.453$, $p<0.013$) (Table 2). No significant association between the MLM and quality of life scores (i.e., SNOT-22 score) was found. In contrast, the LM score demonstrated no association with either symptoms or quality of life in these models (Table 3)

Maxillary sinus MLM scores were found to have a significant effect on TNSS ($\beta=2.38$, $p<0.005$), as were posterior ethmoid MLM scores ($\beta=2.75$, $p<0.005$). A final model was developed based on maxillary, posterior ethmoid, and frontal sinus MLM scores that demonstrated a significant effect on TNSS ($\beta=2.81$ ($p=0.040$), $\beta=2.91$ ($p=0.056$), and $\beta=-2.95$ ($p<0.043$), $R^2=0.226$). None of the combined individual sinus MLM scores was found to correlate significantly with SNOT-22 scores. These results are summarized in Table 4.

DISCUSSION

The results of this study are consistent with a growing trend in the literature that demonstrates the potential utility of volumetric assessment for staging sinus disease [13, 14, 16]. The goal of the present study was to develop a computerized approach to the CT-based volumetric quantification of sinonasal mucosal inflammation in order to enhance the utility of imaging for staging CRS. A modified scoring system was proposed and compared with symptom severity and quality of life, both of which were captured immediately prior to clinically indicated CT scans by validated rhinology questionnaires. The MLM scoring system was significantly associated with patient symptoms, but neither the MLM nor the LM systems demonstrated significant association with patient quality of life. In addition to global scores, volumetric data was evaluated by individual sinus; the MLM scores for the maxillary, posterior ethmoid, and frontal sinuses were significantly associated with patient symptoms. To our knowledge, the dataset of 55 patients used in this study represents the largest cohort for a CRS study investigating volumetric image analysis.

Numerous studies have demonstrated the weak correlation between CT findings and symptoms [6, 9, 23, 24, 25, 26]. The significant correlation between patient symptoms and the MLM score makes MLM one of only a few scoring systems that has demonstrated such a relationship [15, 16, 27]. The MLM system benefits from its objective nature and continuous scale. Rather than any intermediate degree of opacification receiving the same score of 1 in the standard LM scoring system, the MLM system allows for varying degrees of opacification to be distinctly quantified. These findings suggest a potential clinical use for the MLM scoring system and the software tool used to generate it.

Prior work has investigated the relationship among mucosal thickening on imaging, endoscopy findings on physical exam, and symptom severity in patients with severe CRS [15, 16, 27] and has focused on improving correlation between CT findings and symptom scores for patients with a narrow spectrum of severe disease defined by strict criteria. In

contrast, the patients included in the present study were not confined to those with CRS and had relatively low burden of sinus inflammation (mean LM score of 3.9 relative to previous studies with an average LM score of 4.3 in patients without CRS and 9.8 in patients with CRS [28, 29]). The present patient cohort included those receiving a sinus CT scan for any reason, not specifically patients with diagnosed CRS or longstanding sinonasal pathology. Studying patients with low levels of disease may have made it difficult to find associations with quality of life. For example, it is well known that many asymptomatic patients have incidental CT findings such as mucosal thickening [30, 31, 32]. This heterogeneity and lack of focus on severe sinus disease may have contributed to the failure of this study to achieve statistical significance for quality of life, but the significant correlation between inflammation volume and symptom severity becomes even more notable. With entry criteria similar to those of previous studies, the MLM score could prove even more closely associated with symptoms. Repeating this study in patients with defined rhinologic conditions (e.g., CRS with and without polyposis) across a range of clinically relevant and increased severities is the subject of planned future work.

Staging systems such as Lund-Mackay and Zinreich give equal weight to each sinus cavity in the total score. Holbrook et al. [33] attempted to identify potential surrogate markers of disease on imaging, other than diffuse mucosal thickening, such as segmental opacification, sinus cavity size, and hallmark anatomic variations associated with impeded sinus ostia drainage [34]; they failed, however, to show a meaningful association between opacification and various anatomic sites with patient symptoms. The results of the present study suggest that opacification in specific paranasal sinuses (namely, the maxillary and ethmoid sinuses) are most related to symptoms, a finding that matches clinical experience [30, 31]. Therefore, weak correlation between CT-based staging systems and patient symptoms could be the result of less important sinuses being weighted the same as more influential sinuses; perhaps a weighted model based on anatomic location would improve imaging correlation with clinical symptoms. Indeed, Sedaghat et al. [27] described a weighted model for radiologic assessment of the paranasal sinuses and found (with a technique that did not involve volumetric analysis) that although Hounsfield unit (HU) values and LM scores alone were not correlated with symptoms, an HU-weighted LM scoring system was correlated with symptoms. Software tools may make a volumetric weighted model feasible and strengthen correlation between MLM scores and symptom severity, but future studies with a more comprehensive assessment of all paranasal sinuses targeted at proposed weighted models are necessary to support this idea.

The software, although semi-automated, requires manual outlines of each CT image prior to the automated calculation of opacified volume. The potentially labor-intensive manual component limits the practicality of clinical deployment at this time. Moreover, the software currently is unable to assess inflammation within the OMC due to the inherent complexity of this clinically relevant anatomic location. The omission of the OMC limits the robustness of the volumetric analysis technique. Future work will refine the software to include the OMC and increase the level of automation.

CONCLUSIONS

This study demonstrated the potential utility of a modified scoring system that incorporates a CT-volume assessment of sinonasal inflammation as a potential biomarker for staging sinus disease. Significant correlation of this system with standardized subjective measures was found, which supports the role of mucosal inflammation in causing sinus symptoms. Further study is required to investigate the full potential and future applications of this system, especially in CRS patients, and the software tool used to capture the relevant quantitative information. Overall, these findings demonstrate promise for the use of CT-based volumetric analysis of sinus mucosal inflammation as an objective biomarker for clinical trials, pharmaceutical development, and objective monitoring of clinical improvement after medical or surgical intervention for CRS.

Acknowledgments

The authors would like to thank Gregory A. Christoforidis, M.D. for useful discussions and intellectual contributions. MR and JG were supported by the Pritzker School of Medicine; JG received funding from the Icahn School of Medicine. JMP received funding from the National Institute on Aging and the National Institute of Allergy and Infectious Disease (AG036762; AI106683). This work was also supported, in part, by a Preclinical Pilot Translational Study Award from The University of Chicago Institute for Translational Medicine.

Acronyms used

LM	Lund-Mackay
MLM	Modified Lund-Mackay
CRS	chronic rhinosinusitis
TNSS	Total Nasal Symptom Score
SNOT-22	Sinonasal Outcomes Test
FDA	Food and Drug Administration
CT	computed tomography
QOL	quality of life
3D	three dimensional
OMC	ostiomeatal complex
HU	Hounsfield Units

REFERENCES

1. Bhattacharyya N. Incremental health care utilization and expenditures for chronic rhinosinusitis in the United States. *Ann Otol Rhinol Laryngol.* 2011; 120(7):423–427. [PubMed: 21859049]
2. Rosenfeld RM, Andes D, Bhattacharyya N, et al. Clinical practice guideline: adult sinusitis. *Otolaryngol Head Neck Surg.* 2007; 137(3 Suppl):S1–31. [PubMed: 17761281]
3. Cornelius RS, Martin J, Wippold FJ 2nd, et al. ACR appropriateness criteria sinonasal disease. *J Am Coll Radiol.* 2013; 10(4):241–246. [PubMed: 23420025]
4. Bhattacharyya N. The role of CT and MRI in the diagnosis of chronic rhinosinusitis. *Curr Allergy Asthma Rep.* 2010; 10(3):171–174. [PubMed: 20425010]

5. Oluwole M, Russell N, Tan L, Gardiner Q, White P. A comparison of computerized tomographic staging systems in chronic sinusitis. *Clin Otolaryngol Allied Sci.* 1996; 21(1):91–95. [PubMed: 8674232]
6. Stewart MG, Johnson RF. Chronic sinusitis: symptoms versus CT scan findings. *Curr Opin Otolaryngol Head Neck Surg.* 2004; 12(1):27–29. [PubMed: 14712116]
7. Lund VJ, Mackay IS. Staging in rhinosinusitis. *Rhinology.* 1993; 31:183–184. [PubMed: 8140385]
8. Hopkins C, Browne JP, Slack R, Lund V, Brown P. The Lund-Mackay staging system for chronic rhinosinusitis: how is it used and what does it predict? *Otolaryngol Head Neck Surg.* 2007; 137(4): 555–561. [PubMed: 17903570]
9. Metson R, Gliklich RE, Stankiewicz JA, et al. Comparison of sinus computed tomography staging systems. *Otolaryngol Head Neck Surg.* 1997; 117(4):372–379. [PubMed: 9339799]
10. Wabnitz DA, Nair S, Wormald PJ. Correlation between preoperative symptom scores, quality-of-life questionnaires, and staging with computed tomography in patients with chronic rhinosinusitis. *Am J Rhinol.* 2005; 19(1):91–96. [PubMed: 15794082]
11. Zinreich SJ. Imaging for staging of rhinosinusitis. *Ann Otol Rhinol Laryngol Suppl.* 2004; 193:19–23. [PubMed: 15174756]
12. Okushi T, Nakayama T, Morimoto S, et al. A modified Lund-Mackay system for radiological evaluation of chronic rhinosinusitis. *Auris Nasus Larynx.* 2013; 40(6):548–553. [PubMed: 23751774]
13. Reitzen SD, Wang EY, Butros SR, Babb J, Lebowitz RA, Jacobs JB. Three-dimensional reconstruction based on computed tomography images of the frontal sinus drainage pathway. *J Laryngol Otol.* 2010; 124(3):291–296. [PubMed: 19922707]
14. Deeb R, Malani PN, Gill B, et al. Three-dimensional volumetric measurements and analysis of the maxillary sinus. *Am J Rhinol Allergy.* 2011; 25(3):152–156. [PubMed: 21679525]
15. Likness MM, Pallanch JF, Sherris DA, Kita H, Mashtare TL Jr, Ponikau JU. Computed tomography scans as an objective measure of disease severity in chronic rhinosinusitis. *Otolaryngol Head Neck Surg.* 2014; 150(2):305–311. [PubMed: 24301090]
16. Pallanch JF, Yu L, Delone D, et al. Three-dimensional volumetric computed tomographic scoring as an objective outcome measure for chronic rhinosinusitis: clinical correlations and comparison to Lund-Mackay scoring. *Int Forum Allergy Rhinol.* 2013; 3(12):963–972. [PubMed: 24106202]
17. Armato SG III, Grusauskas NP, MacMahon H, Torno MD, Li F, Engelmann RM, Starkey A, Pudela CL, Marino JS, Chang PJ, Giger ML. Research imaging in an academic medical center. *Academic Radiology.* 2012; 19:762–771. [PubMed: 22480961]
18. Hopkins C, Gillett S, Slack R, Lund VJ, Browne JP. Psychometric validity of the 22-item Sinonasal Outcome Test. *Clin Otolaryngol Off J Ent-Uk Off J Neth Soc Oto-Rhino-Laryngol Cervico-Facial Surg.* Oct. 2009; 34(5):447–54.
19. Fairley JW, Yardley MPJ, Durham LH, Parker AJ. Reliability and validity of a nasal symptom questionnaire for use as an outcome measure in clinical research and audit. *Clinical Otolaryngology.* 1993; 18:436–437.
20. Starkey A, Sensakovic W, Armato S. Abras: a portable application for observer studies and visualization. *Int. J. CARS.* 2011; 6:S193–5.
21. Sensakovic WF, Pinto JM, Baroody FM, Starkey A, Armato SG III. Automated segmentation of mucosal change in rhinosinusitis patients. *Medical Imaging 2010: Computer-Aided Diagnosis. Proc. Of SPIE.* 7624:76243N–1.
22. Akaike H. A new look at the statistical model identification. *IEEE Transactions on Automatic Control.* 1974; 19:716–723.
23. Nair S. Correlation between symptoms and radiological findings in patients of chronic rhinosinusitis: a modified radiological typing system. *Rhinology.* 2009; 47(2):181–186. [PubMed: 19593976]
24. Ryan WR, Ramachandra T, Hwang PH. Correlations between symptoms, nasal endoscopy, and in-office computed tomography in post-surgical chronic rhinosinusitis patients. *Laryngoscope.* 2011; 121(3):674–678. [PubMed: 21305550]
25. Jones NS. CT of the paranasal sinuses: a review of the correlation with clinical, surgical and histopathological findings. *Clin Otolaryngol Allied Sci.* 2002; 27(1):11–17. [PubMed: 11903365]

26. Zheng Y, Zhao Y, Lv D, et al. Correlation between computed tomography staging and quality of life instruments in patients with chronic rhinosinusitis. *Am J Rhinol Allergy*. 2010; 24(1):e41–45. [PubMed: 20109323]
27. Sedaghat AR, Bhattacharyya N. Chronic rhinosinusitis symptoms and computed tomography staging: improved correlation by incorporating radiographic density. *Int Forum Allergy Rhinol*. 2012; 2(5):386–391. [PubMed: 22550029]
28. Ashraf N, Bhattacharyya N. Determination of the “incidental” Lund score for the staging of chronic rhinosinusitis. *Otolaryngol Head Neck Surg*. 2001; 125(5):483–486. [PubMed: 11700446]
29. Bhattacharyya N, Fried MP. The accuracy of computed tomography in the diagnosis of chronic rhinosinusitis. *Laryngoscope*. 2003; 113(1):125–129. [PubMed: 12514395]
30. Jones NS. CT of the paranasal sinuses: a review of the correlation with clinical, surgical and histopathological findings. *Clin Otolaryngol Allied Sci*. 2002; 27(1):11–17. [PubMed: 11903365]
31. Havas TE, Motbey JA, Gullane PJ. Prevalence of incidental abnormalities on computed tomographic scans of the paranasal sinuses. *Arch Otolaryngol Head Neck Surg*. 1988; 114(8):856–859. [PubMed: 3390327]
32. Flinn J, Chapman ME, Wightman AJ, et al. A Prospective analysis of incidental paranasal sinus abnormalities on CT head scans. *Clin Otolaryngol*. 1994; 19:287–289. [PubMed: 7994882]
33. Holbrook EH, Brown CL, Lyden ER, Leopold DA. Lack of significant correlation between rhinosinusitis symptoms and specific regions of sinus computer tomography scans. *Am J Rhinol*. 2005; 19(4):382–387. [PubMed: 16171173]
34. Fadda GL, Rosso S, Aversa S, Petrelli A, Ondolo C, Succo G. Multiparametric statistical correlations between paranasal sinus anatomic variations and chronic rhinosinusitis. *Acta Otorhinolaryngol Ital*. 2012; 32(4):244–251. [PubMed: 23093814]

Figure 1.

(a) Manually segmented outlines of the anatomic boundaries of the maxillary sinuses on a single CT section image using ABRAS (blue). (b) Volumetric analysis is performed by combining the sinus outlines from all CT sections in a scan to yield a 3D rendering (yellow).

Table 1

Subject demographics, LM scores, quality of life scores, and symptom scores (n=55)

Mean Age (years)	50.5±15.1
Male/Female (n)	25/30
Tobacco Use (n)	10
Median LM score (w/o OMC) (range)	2 (0-18)
Median SNOT-22 (range)	37 (0-80)
Median TNSS (range)	4.0 (0-12)

Table 2

Multivariate linear regression models for MLM scores.

Model MLM	A	B	C
TNSS	$\beta_1 = 0.437$ (p=0.014)	$\beta_1 = 0.435$ (p=0.018) *	$\beta_1 = 0.453$ (p=0.013) *
Age		$\beta_2 = 0.012$ (p=0.702)	$\beta_2 = 0.015$ (p=0.635)
Gender		$\beta_3 = -0.259$ (p=0.789)	$\beta_3 = -0.187$ (p=0.845)
Tobacco Use			$\beta_4 = -1.85$ (p=0.135)

* Denotes statistically significant β coefficient (p<0.05).

Table 3

Linear regression models for LM (w/o OMC) and MLM vs. TNSS and SNOT-22.

Model	LM (w/o OMC)	MLM
TNSS	$\beta = 0.314$ (p=0.108)	$\beta = 0.437$ (p=0.014) *
SNOT-22	$\beta = 0.023$ (p=0.383)	$\beta = 0.042$ (p=0.082)

* Denotes statistically significant β coefficient (p<0.05).

Table 4

Multivariate regression models for TNSS based on specific sinus MLM scores.

Model TNSS	A	B	C	D
Maxillary MLM score	$\beta_1 = 2.38$ (p=0.005) *	-	-	$\beta_1 = 2.81$ (p=0.040) *
Posterior ethmoid MLM score	-	$\beta_2 = 2.75$ (p=0.005) *	-	$\beta_2 = 2.91$ (p=0.056)
Frontal MLM score	-	-	$\beta_3 = 1.22$ (p=0.168)	$\beta_3 = -2.95$ (p=0.043) *

* Denotes statistically significant β coefficient (p<0.05).